Heavy Vehicle Propulsion Materials

Thermal Oxidation: A Promising Surface Treatment for Titanium Engine Parts

Material	Non-treated Ti_6Al_4V	Thermally Oxidized Ti_6Al_4V	Improvement
Hardness (HK, GPa)	3.3	22.7	7 Times Harder!
Friction Coefficient	0.37	0.11	70% Lower!
Wear Rate (mm^3/N-m)	3.7×10^{-4}	5.9×10^{-9}	60,000 Times Lower!

Figure 1. *Friction and wear results for non-treated and thermally-oxidized Ti6Al4V alloy against a Cr-plated ring in 15W40 diesel oil.*

Background

Recent advances in lower-cost titanium (Ti) processing, coupled with its potential use as a lightweight material in heavy-duty diesel engines and brakes, has prompted interest in friction and wear-related applications for Ti alloys.

Originally developed for aerospace use, Ti alloys offer an excellent combination of mechanical properties and corrosion resistance; however without protection, they tend to gall when rubbed against other metals. Attempts to lubricate Ti met with limited success. Tests at the Oak Ridge National Laboratory (ORNL) have shown that conventional 15W40 diesel engine oil does not effectively lubricate Ti-6Al-4V, the most popular Ti alloy. While Ti-6Al-4V is stronger and harder than gray cast iron, it exhibited three times the friction coefficient and wore 2,000 times faster than cast iron, when tested against production grade Cr-plated diesel engine piston rings. Thus, Ti alloys are good candidates for advanced surface engineering.

Processing and cost limitations of sophisticated surface treatments and coating methods limit their use on titanium alloys in certain friction and wear applications.

Technology

Thermal oxidation (TO) offers the potential to significantly improve the wear resistance of Ti alloys while also reducing friction. Heat treating a Ti alloy to several hundred degrees Celsius in either air or a binary gas mixture, produces a micrometer-thick TiO_2 surface layer and an underlying oxygen-enriched layer. The TO process is relatively simple to apply,

Benefits

- Thermal oxidation dramatically lowers the friction and wear of Ti alloy surfaces.
- Thermal oxidation is relatively simple to apply, low cost, and not restricted by part shape or size.
- Thermal oxidation enables certain lubricant additives which were designed for iron-based alloys to work on titanium alloys as well.

is inexpensive, and is not so restricted to simple shapes as are many other coating methods.

Recent friction and wear tests in diesel oil, conducted at ORNL, revealed impressive benefits of TO. As Figure 1 indicates, when compared with bare Ti-6Al-4V, the friction coefficient of the treated alloy was reduced by more than three times, and the wear rate was even more impressively reduced.

Ti-6Al-4V specimens were thermally oxidized, then tested using ASTM G 181-04, a new standard practice for diesel engine piston ring and liner friction testing that was recently developed at ORNL under DOE sponsorship.

The TO surface was much harder, had lower friction coefficient and astonishingly low wear compared with the bare alloy. Figure 2 shows a marked decrease in wear damage from using TO.

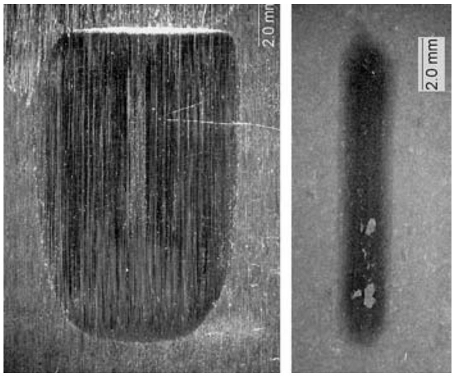

***Figure 2.** Wear scars on non-treated (left) and thermally-oxidized (right) Ti6Al4V.*

Compared to conventional cast iron, the TO-treated Ti-6Al-4V had comparable friction, but 1,000 times less wear. These results far exceed expectations based on the research published by others. Remarkably, the oxygen diffusion layer beneath the titanium dioxide crust has good friction and wear behavior even after the crust was worn through. That observation flies against assumptions that failure of the oxide layer marks the end of useful life.

Surface chemical analyses are beginning to elucidate the basic science of how TO works on titanium alloys. This research is a promising new advance toward light-weight, corrosion-resistant engines of the future.

Status

As simple and cost-effective as it is, thermal oxidation has a great untapped potential to expand the use of Ti alloys for wear- and friction-critical bearing surfaces, like heavy-duty diesel engines. Future commercialization options are being explored.

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